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Multi-sector mitigation strategies at the neighbourhood scale

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ABSTRACT

Climate change mitigation in urban areas requires a portfolio of policies and practices that are implemented across a range of scales and sectors. The local scale allows the development and implementation of site specific strategies to address climate change in urban areas that have been proven to be more efficient, especially within buildings. But these must be within the wider context of transport and other energy consumption. A unique integrated assessment methodology for the analysis of energy at the neighbourhood scale that considers the key sectors of buildings, transport and outdoor lighting has been developed. The influence of key drivers of energy consumption: land use, technology, infrastructure design, are considered to assess how neighbourhood choices impact upon wider energy usage, such as transport emissions. Applied to a neighbourhood in Italy, results show that building retrofit has the greatest benefit, of up to 60%. However, by transitioning to a mixed land use neighbourhood, growing local employment and improving the transit network, reductions of 80% can be achieved in line with the requirements of the Paris Agreement. The method highlights the importance of taking a multi-sector and multi-scale approach to considering neighbourhood mitigation.

1. Introduction

Cities concentrate people, buildings and infrastructure, consequently they are drivers of climate change through their greenhouse gas emissions and also focal points for the impacts of climate change (e.g. Bulkeley et al., 2011). Consequently, climate change has been driving the sustainability agenda in cities, including the incorporation of novel policies to meet low carbon objectives. Environmental, social and economic aspects and interactions of sustainable development need to be considered together, since with an integrated approach, efforts and costs are minimized and trade-offs more likely to be avoided (Swart et al., 2003; Caparros-Midwood et al., 2015, 2017). In addition, the need to recognize and promote synergies between sectors is more evident if both spatial and temporal scales and complexities of urban systems are taken into consideration (Dawson, 2011).

Cities play a key role in contributing to greenhouse gas (GHG) emissions in the atmosphere, while at the same time being vulnerable to the impacts of climate change. Conversely, cities have the opportunity to implement mitigation strategies, which, in the context of urban planning, require an integrated approach across a range of sectors, and over multiple temporal and spatial scales (Pasimeni et al., 2014).

Buildings, transport and industry are typically the most energy intensive sectors in urban areas, responsible for the consumption of about 75% of primary energy and about 60% of CO_2 emissions globally (UN-Habitat; IEA, 2008). Tackling these sectors is therefore a global priority to meet the United Nations Framework Convention on Climate Change Paris Agreement to keep a global temperature rise this century well below 2 °C above pre-industrial levels. Investigation of energy use and reduction measures in these sectors have traditionally been investigated independently, neglecting the potential for working towards urban sustainability by considering them in an integrated manner. In particular, there has been particular interest in analysing the building sector and residential energy consumption. A number of bottom-up and a top-down approaches have been developed. In their review, Swan and Ugursal (2009) described bottom-up models and classified them according to the methods and data used to model the energy

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consumption in buildings. Theodoridou et al. (2012) provide a flexible tool, combining engineering and statistical bottom-up approaches that enables design of suitable energy-conservation interventions on building stocks in Greek cities. Fracastoro and Serraino (2011) provide an analytical methodology that defines a statistical distribution of residential buildings according to their energy consumption for heating at a regional or national scale. The procedure enables evaluation of the energy saving potential of large-scale actions on buildings which aims to support policy-makers to develop energy policies. Sandberg et al. (2016) developed a dynamic statistical model to assess Europe-wide changes to residential building stock. Caputo et al. (2013) developed a methodology to analyse energy performance of the building stock and to assess the implementation of several energy policies in Italian cities. The procedure includes the collection of both statistical and general data on the built environment, the characterization of the building stock and the arrangement of archetypal buildings to estimate energy consumption and appropriate retrofit strategies. Jorge Rodríguez-Álvarez (2016) presented a tool (Urban Energy Index for Buildings - UEIB) to assess the energy performance of buildings at a larger scale. The model allows morphological aspects to be considered independently from other factors. To this end, a notional grid is performed to simplify the main spatial parameters regarding the energy performance of the analysed urban areas. This easy-to-use tool aims at helping the incorporation of energy aspects into urban and spatial policies.

Alongside these energy models developed at the building scale, integrated assessment methods (IAM) and frameworks enable linkages across several scales (global, regional and local) and interactions between sectors from an urban planning perspective. Through this multidisciplinary approach, trade-offs and combined effects that a single disciplinary approach would miss can be identified. However, IAM is more complex than individual sectoral assessment and often leads to bespoke or site-specific applications. A range of urban IAMs were reviewed by Köhler et al. (2014). One example the Urban Integrated Assessment Facility developed for London. This is a quantified integrated assessment framework which combines economy, land use and carbon emissions from energy use and transport and assesses several climate impacts (Hall et al., 2009; Walsh et al., 2011, 2013). The London study involved stakeholders throughout the whole development process and was developed by an interdisciplinary team to address the multiplicity of topics and skills needed (Walsh et al., 2013). Other models, such as Linz (Köhler et al., 2014), consider energy demand and emission levels over a shorter time horizon, to suggest guidelines for development of new towns. In Paris, (Viguie and Hallegatte, 2012) used an integrated city model to quantify trade-offs and synergies of policies. In particular, a multicriteria analysis was undertaken for three urban policies: a greenbelt policy, a zoning policy to reduce flood risk and a transportation subsidy, showing that in a policy mix, the consequences of each policy were not simply additive. This nonlinearity permitted building policy combinations. IAMs allow the relationships between different sectors to be explored in a consistent manner, and climate change processes to be linked to urban planning and policy processes.

Furthermore, IAMs can be used as supporting tools for political and technical decision-making processes, in which scenario analysis may play a key role for a deeper understanding of urban environments. Scenario approaches are increasingly being employed in urban planning as they provide an integrated, and future-oriented, approach to thinking about urban transformation (Stojanović et al., 2014).

Methodologies for urban scenario configuration have not been developed unequivocally. On the contrary, there are numerous different typologies and techniques that are chosen according to objectives and specific territorial contexts.

In this paper, the gap between the bottom-up residential building analysis and top-down city-scale IAMs is bridged through development of a unique neighbourhood scale assessment. Unlike many IAMs that perform analysis at regional and city level, this study has a local, neighbourhood focus, which is suitable for both energy and sustainability assessment since it constitutes an intermediate scale between individual buildings and the city. A set of urban scenarios at the local scale are developed to investigate the sustainability and the energy performance of neighbourhoods. This analysis integrates across the key sectors of buildings, transport and outdoor lighting in order to investigate the potential of neighbourhoods in developing both energy saving and efficiency actions in the framework of spatial planning strategies. Buildings and lighting energy consumption are analysed by considering activity within the neighbourhood boundary. However, transport energy use requires consideration of how neighbourhood residents access jobs, services and other activities outside their neighbourhood. Thus, the analysis considers multiple scales to both assess the overall energy consumption of and understand how to mitigate greenhouse gas emissions from neighbourhoods.

Scenarios are used to explore how planning and technological drivers influence the sectors of buildings, transport and outdoor lighting, prime consumers of urban energy. Pathways towards decarbonisation are investigated through sensitivity analysis of several measures that are selected for specific sectors, but which interact with other sectors. Energy assessments of the three sectors are undertaken through extension and application of the integrated model that has been developed, but not previously applied for mitigation strategy development, by the authors (Fichera et al., 2016).

In the following sections, the methodological approach is described. This includes a brief description of the model, the selection of the drivers of change in the urban systems from an energy perspective, and the rationale of the sensitivity analysis. The framework is applied to a neighbourhood in the city of Catania, Southern Italy, before results are discussed, and conclusions drawn in the final section.

2. Material and methods

2.1. Modelling approach

The study presented in this paper extends a model developed by Fichera et al. (2016) that assesses the overall urban energy consumption of a neighbourhood from its building, transport and outdoor lighting sectors.

The structure of the model is fully described by Fichera et al. (2016); however, the key elements are summarised below. This integrated model was originally developed to calculate the current energy performance of urban areas, here we have further developed the model, and embedded it within a scenario framework, to understand the impact of changes in the urban area and to assess the effectiveness of mitigation strategies.

For the building sector both thermal and electrical energy consumption are assessed. The first is characterised by the energy performance index (EPI), which provides an indication of thermophysical properties of both the envelope and the thermal system of buildings. The indicator is yielded through the calculation of the space heating demand of buildings with a bottom-up, individual building approach led by a simplification of the Italian standard procedure (DM, 2009) and standard UNI-TS 11300 (UNI, 2008a; UNI, 2008b). Electrical energy is calculated by processing statistical data about both census track and electricity consumption of buildings.

The transport sector is characterised by a simple land use and transport sub-model that computes a commuting transport energy indicator (TED), based on a reduced complexity trip generation model, a transport mode choice model and an optimal assignment of worker flows to job destinations. The transport energy dependence indicator, (TED), is a measure of the minimum energy used for commuting journeys in ideal conditions; therefore, it is a simple indicator of the minimum transport energy used if people would select the most energy efficient mode of transport available according with simple rules based on the distance between land use locations.

Finally, the model provides the assessment of energy consumption from the outdoor lighting sector by examining the city database of street lighting, in particular data collected for the Sustainable Energy Action Plan, which includes information about the characteristics of lamps. The outdoor lighting sector is an assessment of electrical energy consumption per unit area of streets and public spaces through the Lighting Index indicator.

2.2. *Drivers of change*

Urban areas and local neighbourhoods are the smallest geographical scales where sustainability issues can be tackled in an integrated and holistic way (Berardi, 2013). Within cities, interactions take place between land use, infrastructure systems and the built environment at a range of scales from city-wide to individual buildings (Walsh et al., 2011). The energy flows resulting from each of these aspects varies according to a range of characteristics.

Firstly, exogenous factors that may have potential impacts on the energy consumption of the neighbourhood, are identified. Here, population and economic characteristics can directly influence the urban morphology, land use, infrastructure design and technology, which are considered as direct drivers. In addition, planning policies and individual behaviours are considered as factors that may have influence on, and be influenced by, the direct drivers. Urban morphology significantly impacts upon energy demand and energy efficiency (Ratti et al., 2005; Rode et al., 2014) and on outdoor thermal comfort and air quality (Krüger et al., 2011) at the district level. Land use factors mainly affect building and transport sectors. The influence of the combination of the drivers of land use and morphology on urban performance is visible in energy-intensive sprawled settlements, which show high levels of GHG emissions due to the use of private car for commuting and short-distance journeys (Newman and Kenworthy, 1996; Bigio et al., 2014). As a consequence, both compact urban morphology and mixed-use environments are significant factors that may influence energy consumption of neighbourhoods (Naess, 2005; Dulal et al., 2011; Rode et al., 2014). As far as technology is concerned, technological innovations occur at a differentiated pace and rate of implementation in different sectors. In the transport sector, advancements are achieved in more fuel-efficient engines, in plug-in hybrid and electric vehicles, and in the development of biofuels (EC, 2017). In the building sector, an improvement of the energy performance may be obtained by adopting the passive housing technology in new buildings, by refurbishing the existent building stock (e.g. improvements to building envelopes and heating systems) and by substituting fossil fuels with renewable energy sources (EC, 2017). Finally, the design and provision of urban and transport infrastructures are key elements to address climate change mitigation and adaptation. Moreover, inadequate provision of both energy and transport networks may exacerbate the impacts of climate change in urban areas. Similarly, appropriate design of utility provision may cut carbon emissions (Bulkeley et al., 2011), whilst the design of infrastructures shapes behavioural choices and economic factors. The drivers and their relationships, considered in this analysis, are shown in Fig. 1.

Direct drivers are assumed to induce changes in the urban systems by adopting specific measures, framed in integrated planning strategies, on the sectors. In the model, drivers and measures are represented by altering the values of the parameters that describe the urban energy performance of the three sectors. The impact of these changes is captured by the resultant changes in indicators.

Scenarios are constructed from a combination of measures that may belong either to one or more driver categories (land use, technology and infrastructure design) arranged for the relevant sectors (building, transport and outdoor lighting). Fig. 2 shows a diagram that links the drivers of change and those sectors they influence. Long term morphological change, resulting from building demolition, and major infrastructure reconfiguration are not considered here.

2.3. *Urban scenarios*

Combining drivers allows the configuration of urban scenarios that are representative of strategic and multi-sectoral planning approaches. The direct drivers induce differentiated changes in the

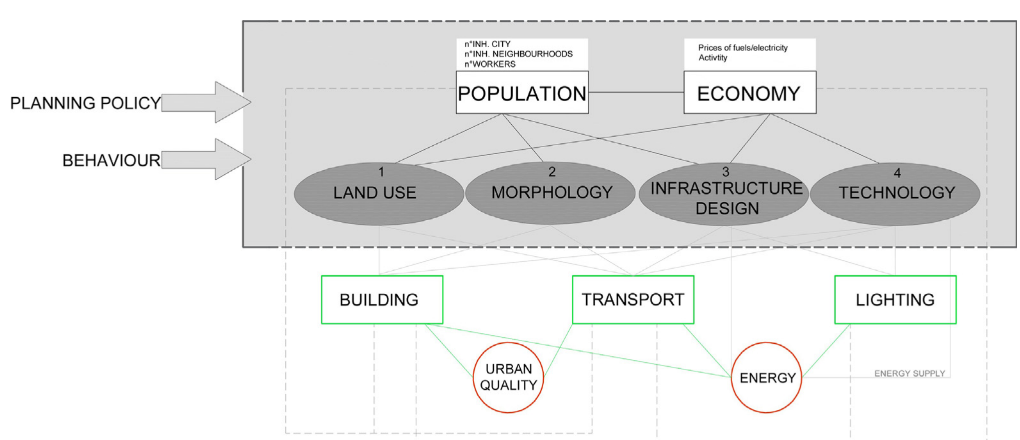

Fig. 1. Direct drivers of change (Population, economy, land use, morphology, infrastructure design, technology), their interaction with urban sectors (buildings, transport, lighting), and outcomes (e.g. energy consumption).

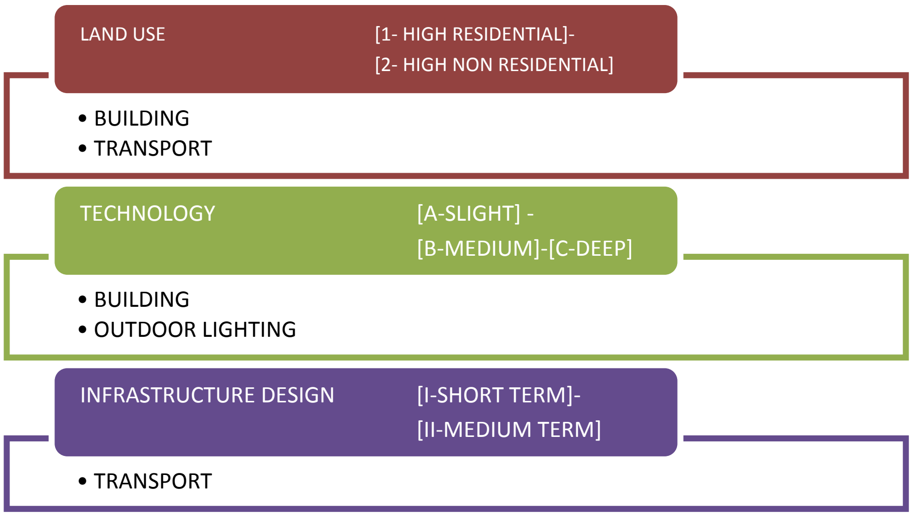

Fig. 2. Scheme of drivers of change and their corresponding sectors.

sectors of the model. In order to assess these changes, sets of measures and conditions for each driver are identified.

Changes in land use may influence energy consumption of both buildings and transport, by varying the number of jobs and employment locations and thereby the energy consumed by commuters. The transport sector is more sensitive to land use changes than the building sector, since the TED, which assesses the minimum energy consumption for commuting journeys when optimal conditions are met, significantly varies as a function of land use. If residential density increases, the number of commuting journeys rise due to an increase in the number of people who work outside the neighbourhood. Conversely, mixed land use indicates a different profile of thermal and electrical energy consumption and a lower number of commuting journeys since the neighbourhood offers a wider range and a larger number of working activities. Therefore, two land-use configurations are considered: (1) high residential and (2) high non-residential. These represent two extreme conditions on which the set of measures rely.

Technology influences all sectors of the model. However, at this stage, only improvements in the building and outdoor lighting sectors are considered. The parameters involved are: the thermo-physical variables for the building sectors (i.e. transmittance, U, of the building envelope describes the insulation capacity of a building structure, and the global efficiency, η, which is a performance measure of the heating system) and the types of lamps for the outdoor lighting sector. Improvement of building energy performance may be gained by limiting the thermal conductivity of major construction elements, which means altering U (expressed in W/m^2K) for the main building elements (BPIE, 2011), and by operating on the thermal systems. Three increasingly substantial sets of measures are considered: (A) Slight: Partial improvement of the building envelope and improvement of the global heating system; (B) Medium: Partial extensive improvement of the building envelope and improvement of the global heating system; (C) Deep: Overall improvement of the building envelope and improvement of the global heating system. For all the three options, replacement of outdoor lamps is included.

Improvements to infrastructure are also considered by a gradual implementation of measures to alter transport networks (road, transit and pedestrian) and modal choice. (I) Slight: incorporates an improvement of infrastructure for pedestrians, such as increasing the catchment area of the bus system by improving access to transit stops, pedestrian safety measures and car traffic calming measures. These measures are achievable over short term periods. (II) Medium: includes the above policies as well as the extension of transit networks, which may be achieved in medium term periods. Deep infrastructure interventions, which might include a major reconfiguration of the network or large scale deployment of autonomous electric vehicles, would be of interest. However, the changes are beyond the analytical capability of existing modelling tools and so have not been assessed in this study. The sets of measures are incorporated in the model by varying specific parameters which are the basis for evaluation of energy consumptions. Fig. 3 shows the conditions and measures assumed for the three drivers of change and the sectors involved and related parameters are listed for each pairs of drivers in Tables 1 and 2.

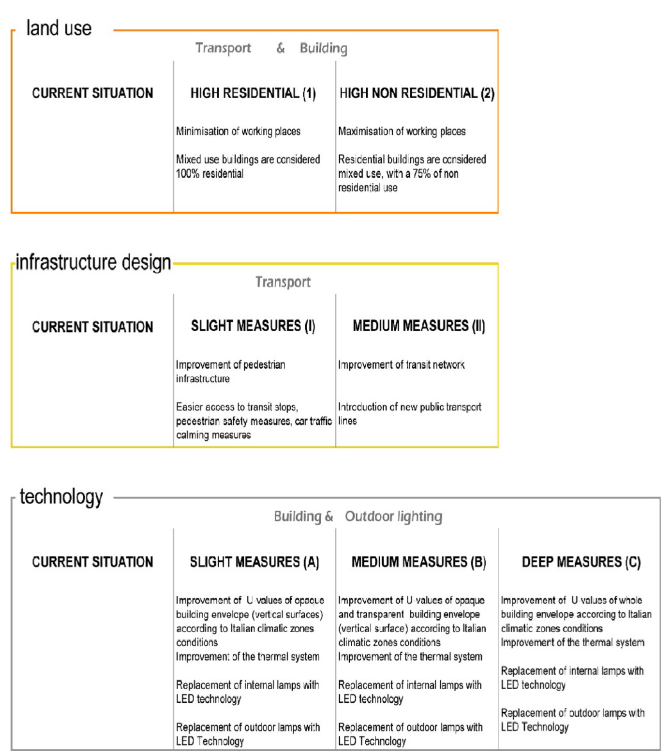

Fig. 3. Characteristics and measures in the framework of the drivers of change.

Table 1
Parameters involved in urban scenarios determined by the combination of the sets of measures for Land Use (High Residential (1) and High Non-Residential (2)) and Technology (Slight (A), Medium (B), Deep (C)) drivers.

Land Use (High residential (1)) – (High Non-Residential (2)) and Technology (Slight (A)) – (Medium (B)) – (Deep (C))			
Buildings		Transport	Outdoor lighting
Size	Envelope Transmittance	Working Population	Type of lamps
Volume	Ventilation	Activities	Power of lamps
Orientation	Energy Performance	Trip frequency	
Climate	Inhabitants	Short distance OD pairs	
System Efficiency	Building Use		
Electric Energy			

Table 2
Parameters involved in urban scenarios determined by the combination of the sets of measures for Land use (High Residential (1) and High Non-Residential (2)) + infrastructure design (Slight (I)) – (Medium (II)).

Land Use (High Residential (1)) – (High Non-Residential (2)) and Infrastructure Design (Slight (I)) – (Medium (II))		
Building	Transport	
Inhabitants	Working Population	Capacity of the vehicle (spaces)
Building Use	Activities	Load factor (pax/spaces)
	Trip frequency	Transit network
	Short distance OD pairs	Road & Pedestrian network
	Unit energy cons transport mode	

The drivers of change can be combined in a number of ways to test a range of urban and neighbourhood futures. So for example land use change may be associated with both technology and infrastructure design, providing 21 combinations in all (Fig. 4). In addition, the most efficient conditions for each driver may be combined, which gives a vision of the most significant energy efficient configuration. For each urban scenario, the model provides a spatial assessment of energy consumption by sector enabling comparison against the baseline scenario.

3. Results and discussion: case study application and urban scenarios

The methodology was applied to the neighbourhood of *Nesima Superiore* (0.67 km^2) in Catania (Fig. 5). The neighbourhood is near the centre of a large conurbation characterized by extensive urban sprawl (La Greca et al., 2011) that, in conjunction with most of the working activities and attractions, polarizes the city of Catania, and influences both the number and type of transport journeys. Catania is located in the Italian Climatic Zone B. There are currently 833 Heating Degree Days (HDD) and the heating period is from 1st December to 31st March. The buildings within the neighbourhood cover a range of ages and show different morphological and land-use types (Fig. 6). A project for a metro line extension to link the area to the city centre is under construction. Outdoor lighting characteristics were gained from the SEAP of the city of Catania (SEAP, 2014). A collection of urban scenarios was developed that represented differentiated profiles of energy consumption and showed some potential future images of the neighbourhood that integrate the quality of urban environment to energy efficiency. In the following paragraph both the specific conditions and the procedures at the basis of the urban scenarios applied to the neighbourhood of Nesima Superiore are described for each driver of change outlined in the previous section.

3.1. Land use

Both land use scenarios take into account the buildings that are suitable for alternative usage. For both residential and mixed-use buildings, the conversion is led by either a decrease or an increase of the percentage of non-residential use. In particular, for condition (1), all the buildings with appropriate geometry characteristics were considered dwellings. For condition (2), the results are yielded assuming that mixed-used buildings are non-residential in terms of electric and thermal energy consumption, since they have a 75% of non-residential rate. Key values are summarized in Table 3.

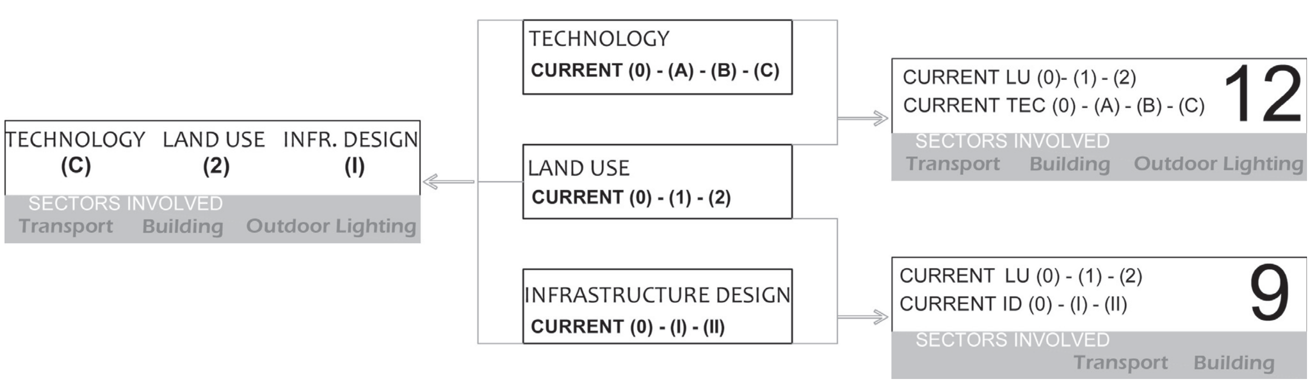

Fig. 4. Configuration of urban scenarios by the combination of drivers and sectors.

Fig. 5. The study area of Nesima Superiore in Catania Metropolitan area (Italy).

Table 3
Summary of results for the extreme conditions of land use drivers of change (High Residential (1) and High Non-Residential (2)).

	Current (0)	High residential (1)	High non- residential (2)
N. dwellings	272	294	102
N. inhabitants	4098	4186	1450
N. Jobs	289	85	1231
N. Workers	897	916	319

3.2. Technology

The improvement of the energy performance of buildings is determined by the characteristics of the building envelope and of the heating system. Here the transmittance value (*U*) is gathered from the recent Italian regulations (D.M. 26/06/2015) and the values for different interventions (Evola et al., 2016) are summarized in Table 4.

The current status of the building stock of the neighbourhood of Nesima Superiore is extremely low: a poor quality of the building envelope and low efficiency heating systems. This is explained by the period of construction of the majority of buildings: from a preliminary investigation it was highlighted that 50% of the building stock was built before 1964 and 35% between 1964 and 1985.

All three conditions include the replacement of lamps in buildings with better performing ones and the improvement of the building heating system, which is represented by the global efficiency parameter ηgl (Table 4).

The implementation of the three sets of measures to the neighbourhood generates three degrees of energy reduction, from 30% to 60%, which are summarized in Table 5.

As far as outdoor lighting is concerned, a reduction of the energy consumption may be obtained by replacing the existing lamps with more efficient types. LED technology, for instance, shows a five-time lower energy consumption than the halogen and incandescence lamps. The variation of the Lighting Index indicator [kWh/m^{2}y] developed in the model for the current situation (Fichera et al., 2016), shows that a reduction of 80% of consumption can be achieved by the replacement of traditional lamps.

3.3. Infrastructure design

The transport analysis takes into account changes to the transport network by considering the spatial relationship between demand and supply. The former is based on the assessment of commuting flows, while the latter includes the road network, composed of 516 nodes and 1122 links; the transit network of 49 bus lines, 4 lines of Bus Rapid transit (BRT) and 1 metro line. The PTV VISUM software package was used to compute the shortest path between all origin and destination pairs by all modes of transport. When more than one transit system option is available, the software calculates the shortest path by a combination of all

Fig. 6. Buildings within the case study area (2016).

Table 4
Values of the parameters involved for the technology driver of change for current situation and for the sets of measures (A - Slight, B -Medium, C- Deep) of the building sector.

Name of parameter	Current (0)	Set of measures (A)	Set of measures (B)	Set of measures (C)
U - Thermal Transmittance of Vertical surfaces (W/m^{2}K)	0.63 < U < 1.57 According to building age and characteristics	U = 0.39 According to building characteristics	U = 0.39 According to building characteristics	U = 0.39 According to building characteristics
U - Thermal Transmittance of Horizontal surfaces (W/m^{2}K)	0.7 < U < 2.0 According to building age and characteristics	0.7 < U < 2.0 According to building characteristics	0.7 < U < 2.0 According to building characteristics	0.3 < U < 0.39 According to building age and characteristics
U - Thermal Transmittance of Windows (W/m^{2}K) (glass and frames)	2.7 < U < 5.0 According to glass and frames characteristics	2.7 < U < 5.0	U = 2.8	U = 2.8
ηgl – Global efficiency of the thermal system	0.54 < *ηgl* < 0.74 According to building age	ηgl = 0.77	ηgl = 0.77	ηgl = 0.77

Table 5
Outcomes in terms of energy reduction of the implementation of the sets of measures for technology in the building stock (CFR Fig 3).

	Current (0)	Slight (A)	Medium (B)	Deep (C)
Thermal Energy [TOE/y]	2070	891.5	712.0	224.0
Electric Energy [TOE/y]	1029.0	964.2	964.2	964.2
Reduction (%)	0%	40%	41.3%	61.6%

Table 6
TED values and energy consumption of the neighbourhood for the infrastructure design sets of measures (Slight and short term (I)) and (Medium and Medium term (II)).

Nesima superiore neighbourhood	TED [MJ/pax week]	TED [MWh/y]
(0) Current situation	6.39	796.39
(I) Short term	5.25	653.47
(II) Medium term	3.07	381.94

modes (Inturri et al., 2014). The city of Catania has been subdivided into 50 zones and the neighbourhood of Nesima Superiore is one of these. The TED for the two transport options (Slight and short term (I)) and (Medium and Medium term (II)) for the neighbourhood are shown in Table 6.

3.4. Urban scenarios

Urban scenarios are derived from various combinations of the drivers. The results are shown in Tables 7 and 8. All the scenarios improve the current situation and can be used to identify best and worst cases of the combined implementation of measures. When the transport sector is set for the high non-residential land use condition (2), keeping technology constant, the TED shows the lowest value. On the contrary, keeping the infrastructure constant, the minimum energy consumption is gained for conditions (C) as far as technology is concerned and for the high residential land use condition (1).

Table 7 shows how changes to land use impact transport energy. However, changes in each zone are not representative of the changes across the whole city. Since transport energy depends on

Table 8
Building sector results in terms of TOE/y for the combination of measures driven by land use and technology.

Building stock energy [TOE]	Current (0)	Slight (A)	Medium (B)	Deep (C)
Current (0)	3099	1855	1676	1188
High Residential (1)	2783	1694	1106	1106
High Non-residential (2)	2933	1821	1703	1218

flows between zones, an increase in the value of TED for the case study area is not necessarily equivalent to an increase of the transport energy of the whole city. Therefore, changes in each zone may have impacts on other zones and on the performance of the whole city. TED values for non-residential conditions show improved results for all the conditions related to the direct driver of infrastructure design. However, this result changes if the normalization per inhabitants is considered. Furthermore, the value of TED decreases progressively according to changes in infrastructures options from current infrastructure design situation to (II). This implies that transformations in transport infrastructures have a positive effect on the energy consumption of neighbourhoods, independently from changes in land use. However, if land use changes are considered, TED further varies, maintaining a decreasing trend according to better conditions of transport infrastructures. The case of infrastructure design for the current

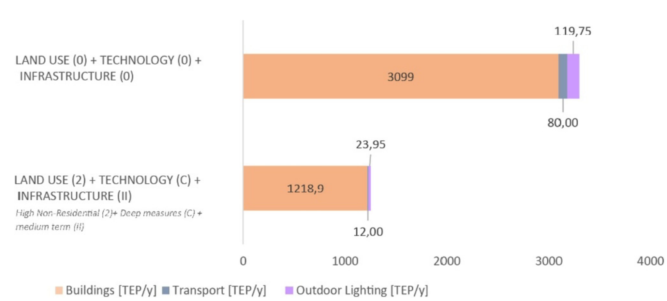

Fig. 7. Comparison between the current situation and the combination of the deepest measures: LAND USE (High Non-Residential (2)) + TECHNOLOGY (Deep-(C)) + INFR. DESIGN (Medium term (II)).

Table 7
Transport sector results in terms of TED for different combinations of transport and land use measures (High Residential (1)) – (High Non-Residential (2)) and infrastructure design (Slight – short term (I)) – (Medium –Medium term (II)).

Nesima superiore neighbourhood	Current Land use (0)			High residential (1)			High non-residential (2)		
	[MJ/pax week]	[MJ/week]	[kWh/y]	[MJ/pax week]	[MJ/week]	[kWh/y]	[MJ/pax week]	[MJ/week]	[kWh/y]
CURRENT (0)	6.39	5734	796388	6.39	5855	813194	0.00	0.00	0.00
Infr. Design (I) Short term	5.25	4705	653472	4.08	3733	518472	5.25	1673	232361
Infr. Design (II) Medium term	3.07	2750	381944	2.97	2723	378194	3.15	1004	139444

situation and high non-residential (2) land use is significant, since it shows a nil value for TED. This result may not be intuitive but it is to be expected as it leads to more jobs than workers and the model tries to minimize TED by assigning people to work in their local neighbourhood, thereby not consuming energy on commutes. Although a high value for TED in the combination of (2)-High Non-Residential in land use and (I)-Short term in transport is recorded, changes in TED values are clear in overall terms, for the 50 zones of Catania. From these considerations, TED indicator results are more sensitive to infrastructure issues than to land-use changes, which strengthens the concept of transport choices as a key factor in planning policies. The measures for land use imply a softer change in the energy consumption of the transport sector than the buildings sector (Tables 7 and 8). The most efficient scenario is yielded by combining the deepest combination of infrastructure, land use and technology ((C) + (II) + (2)). For Nesima, this shows a consumption of about 1219 TOE/y for the building sector, of 23.95 TOE/y for outdoor lighting and a TED value of 12 TOE/y, with a general energy consumption of 1254.85 TOE/y that is 60.6% less than the current situation (Fig. 7).

The outcomes of scenarios are reported in maps of the neighbourhood. In particular, Fig. 8 illustrates the energy map for

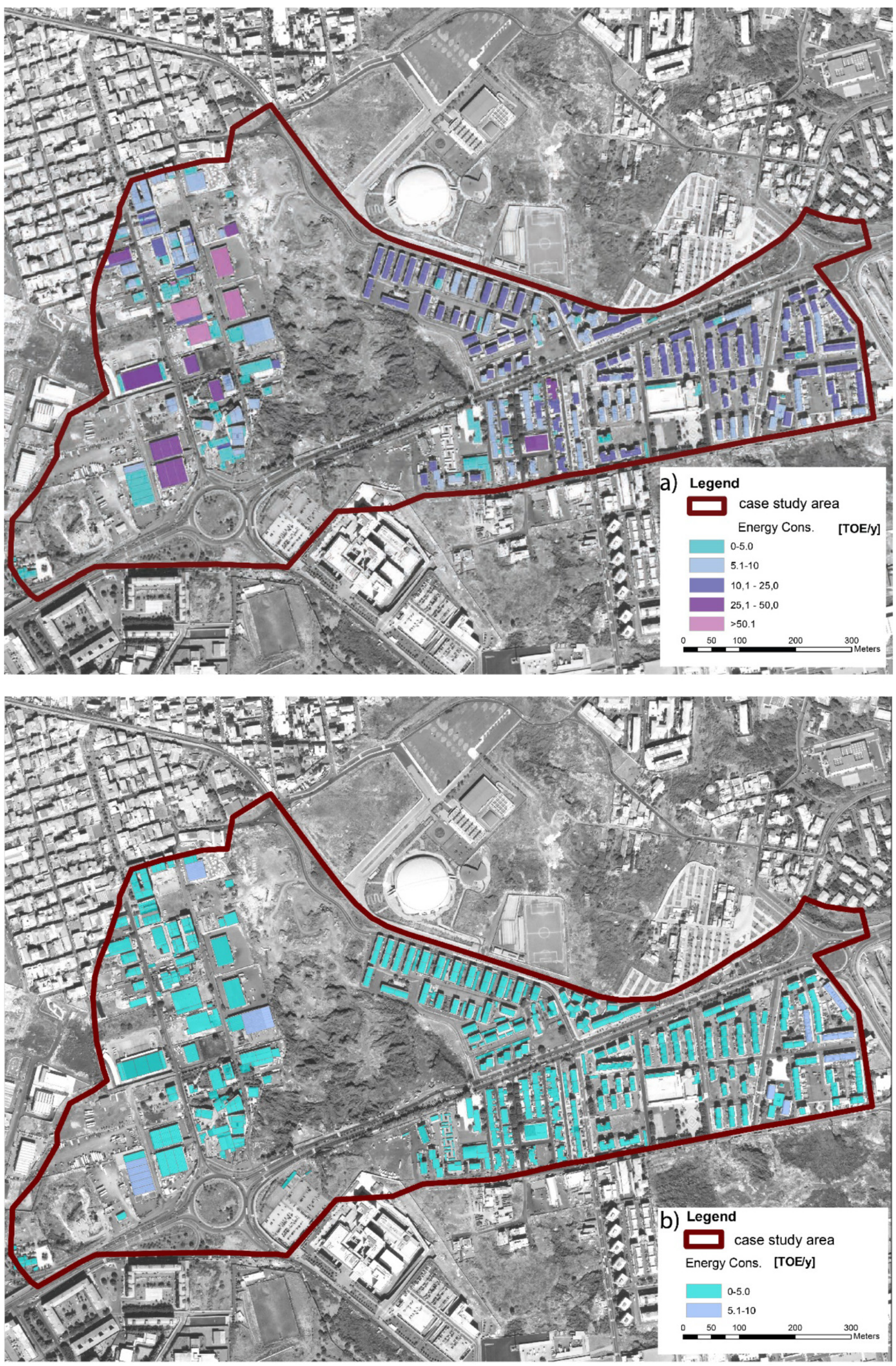

Fig. 8. Energy map for (a) the current configuration, and (b) the combination of LAND USE (2) + TECHNOLOGY (B) + INFR. DESIGN (II).

buildings (b) in the most efficient urban scenario (land use (high non-residential (2)) + technology (deep-(c)) + infr. design (medium term (ii)) compared to the map for the current status of buildings (a). The maps clearly show that the high improvement of the energy performance of buildings for the most efficient urban scenario.

Changes in land use and infrastructure design help to reduce energy consumption from transportation. Table 8 shows that there are not huge differences in the energy consumption of buildings for different configurations of land use. Although the high residential scenario has the lowest building energy consumption, when considering transport energy costs, a balance of residential and non-residential building usage reduces transport energy demand. This is because neighbourhood residents have more opportunity to live, work and access services locally, consequently reducing transport energy requirements.

Scenarios represent the outcomes of significant technology and infrastructure engineering interventions, coupled with residential planning measures that are driven by planning policy. Improvement in energy efficiency could also be gained through the consideration of urban morphological changes. This implies the provision of new modern buildings, characterized by higher energy standards that can be obtained more readily than in the existing building stock. Deep changes to infrastructure or urban morphology are not simulated here as they typically require much longer timeframes or deliberate interventions (Sandberg et al., 2016). Moreover, existing modelling tools are not adapted to cope with such interventions that require consideration of new processes.

Conversely, implementation of the measures considered here for the three sectors are feasible with a portfolio of increasingly progressive policies. For example, changes in land use may be obtained through either slight measures, such as incentive schemes for increasing mixed use, or through deep retrofit, demolition, reconstruction and possible morphological change. In contrast, implementation of technological measures may result from policies aimed primarily at the retrofitting of existing buildings but have impacts on urban areas in general. However, all these actions require time to take effect, and for the alignment of engineering and policy instruments.

4. Conclusions

This paper introduces a novel integrated assessment framework to develop and test multi-sector mitigation scenarios at the neighbourhood scale. This involves bottom-up analysis of buildings and lighting energy consumption, and a city-wide assessment of transport energy demand by neighbourhood residents. Relationships between drivers of change were established to enable a number of different land use, building retrofit and infrastructure scenarios and mitigation strategies to be tested against the baseline energy demand. Urban scenarios represent the outcomes of planning mitigation strategies regarding numerous sectors and drivers of changes and may support policy makers and urban planners in decision making processes.

The approach was applied to the Italian neighbourhood of Nesima Superiore in Catania. Results for the case study show that a significant reduction in the neighbourhood energy demand can be achieved by implementing a portfolio of measures. Given buildings represent the most energy intensive sector, measures aimed at retrofitting the building stock result in significant efficiency. In Italy the building renovation rate is on average 1.5% per annum, which means it requires 70 years for all buildings to be renovated. The transport sector can help reduce energy demand with appropriate changes in land use and infrastructure – notably, this requires development of mixed use neighbourhoods.

The analysis does not consider the relative implementation barriers of different options, which vary significantly between countries and even between neighbourhoods within a city. For example, the building sector is affected by a wide range of financial and regulatory arrangements, further complicated by the large number of actors involved. Typically, transport and outdoor lighting sectors can have fewer key decision-makers, although there are often significant financial barriers, particularly in relation to the level of investment required to implement deeper changes.

The case study focuses on the issues of greatest importance to Nesima Superiore. However, the methodology provides a framework that can be extended to include alternative issues reflecting priorities and processes in other neighbourhoods. With limited budgets for investment, local communities have a key role to play in identifying local priorities for an integrated portfolio of mitigation options. The most successful strategies include provision of local jobs and services, attracting investment to reduce energy costs, and changing behaviours towards energy efficiency. Further development of this research will consider trade-offs and synergies between adaptation and sustainable development goals within neighbourhoods.

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List of abbreviation

GHG: greenhouse gas
UN-Habitat: United Nations Human Settlements Programme
IEA: International Energy Agency
UEIB: Urban Energy Index for Buildings
IAM: integrated assessment methods
DM: Decreto Ministeriale
UNI-TS: Italian National Unification - Technical Specification
TED: Transport Energy Dependance
EC: European Commission
U: Transmittance
BPIE: Buildings Performance Institute Europe
HDD: Heat degree day
SEAP: Sustainable Energy Action Plan
BRT: Bus Rapid transit
LED: Light-emitting diod